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PEACH MOSAIC
ITS IDENTIFICATION AND CONTROL

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INTRODUCTION

A new virus disease of peach trees, similar to peach yellows in its contagious nature, rapidity of spread, and menace to the commercial peach industry, was discovered in 1931 and at present is known to occur in several widely separated districts west of the Mississippi River. In the spring newly formed leaves on trees affected with this disease present prominent areas in which the natural green of the leaf is mottled with yellow. Because this type of mottling is distinct from leaf characters associated with other diseases of the peach, the new disease was named peach mosaic (3).¹

An account of peach mosaic, which includes the discovery of the disease, its infectious nature and classification, known distribution, identification in the field, and control measures, is given in this circular.

Although the authors have worked independently—Hutchins in Texas, Bodine in Colorado, and Thornberry in California—they have kept in close touch with one another and have compared symptoms of the disease over the areas where it is now known to occur. It is believed that the symptomatology of peach mosaic may be more satisfactorily treated in this circular by joint authorship than would be

¹ Italic numbers in parentheses refer to Literature Cited, p. 48.

possible if each investigator were to publish his work separately. Throughout the discussion the name of each author is used as needed to indicate his respective contributions to the information reported.

DISCOVERY

In July 1931 Hutchins' attention was called to an obscure new disease of the peach in Texas by William F. Turner, in charge of field work of the phony-peach eradication campaign, Bureau of Plant Industry, United States Department of Agriculture. With the cooperation of the Texas State Department of Agriculture, Mr. Turner and inspectors at the time were conducting an extensive phony-peach survey in that State which brought them in contact with growers, nurserymen, and others, and which covered the principal peach-producing districts. In orchards near Bangs, in Brown County, and Clyde, in Callahan County, a number of trees were found that exhibited profuse branching of the smaller limbs (fig. 1), abnormal leaf growth, and bumpy, misshapen fruit. A few growers already were familiar with the new disease and stated that they had observed it during the previous 4 or 5 years.

INFECTIOUS NATURE AND CLASSIFICATION

Fresh roots and twigs collected from some of the trees at Bangs and at Clyde that showed the disease in its most characteristic form were used as a source of inoculum in tests on transmissibility of the disease (3). On July 15 and 16, 1931, under conditions that precluded the possibility of accidental infection, peach nursery trees growing in pots were variously inoculated. Thirty-four trees were budded with buds from mosaic-diseased trees, 16 trees were inoculated by grafting diseased root bark on the root, and 6 trees were inoculated by grafting diseased root bark on the stem.

A high percentage of these bud and root-bark graft inoculations formed good unions. The inoculated trees were vigorous, but the inserted buds were not forced in 1931, and no pathological symptoms appeared in any of the inoculated plants in that year. With the beginning of growth in the spring of 1932, symptoms of a virus disease were apparent in the new shoots from all aerial parts of the successfully inoculated trees and in new sucker growth from the roots. The most significant growth characters were short internodes, profuse branching, and variously formed leaves that were mottled with yellow. That infection is systemic in the diseased tree was indicated by the fact that transmission was secured (1) from diseased buds grafted on healthy shoots, (2) from diseased root bark grafted on healthy shoots, and (3) from diseased root bark grafted on healthy roots.

For a few of the trees in which inoculation was attempted, none of the bud or patch-bark grafts made growth unions. The disease was not transmitted in these cases, and all shoot growth from such trees remained normal. Tests of bark and wood tissues from diseased trees on artificial culture media failed to show the presence of a bacterial or a fungus parasite.

Some of the most prevalent types of mottling that appeared in the leaves of successfully inoculated plants are discussed on page 12.

This feature of the disease is illustrated in some detail because of its value as a reliable symptom in spring, and because it suggested the name "peach mosaic."



FIGURE 1.—Twig from an old case of peach mosaic in a Texas orchard, showing branched character of current season's twig growth. Leaves removed as necessary to expose twigs. Similar twigs furnished inoculum for proving the virus nature of the disease. (Photographed July 16, 1936.)

From symptoms of this disease in the field and from its behavior in inoculation experiments, therefore, peach mosaic is now definitely classified in the group of infectious virus diseases.

For the purposes of the present discussion, a virus may be thought of as an exceedingly minute infective principle, smaller than the bacteria, and not visible even under the highest magnifications of the microscope.

In general, viruses are capable of rapid multiplication in the host, and individually or in combination they are the cause of some of the most serious and most contagious diseases of cultivated plants, domestic animals, and man. Mosaic or streak diseases caused by viruses are familiar to many growers of sugarcane, tobacco, vegetables, small fruits, and ornamental plants. Hog cholera, foot-and-mouth disease, and rabies are well-known virus diseases of animals. Smallpox, chickenpox, mumps, and measles are common virus diseases of man.

Dissemination or spread of plant virus diseases in nature is accomplished by mechanical means, or by living agencies called vectors. For some of these diseases the vector is known to be specific, and in many instances it is an insect.

In many sections east of the Mississippi River, peach growers have long been subjected to ruinous losses from one or more of the virus diseases of this plant. Peach yellows and little peach are old and familiar diseases in the northeastern quarter of the United States, and red suture has recently attracted much attention in certain parts of this area. Peach rosette and phony disease are known particularly in the Southeast.

West of the Mississippi River, virus diseases of the peach have not attracted serious attention until recently. Peach rosette has been reported occasionally from points in the eastern portion of this area, and within the last few years phony disease has appeared in Louisiana, Texas, Arkansas, Oklahoma, and Missouri.

KNOWN DISTRIBUTION

No information is available to indicate precisely the year when peach mosaic made its first appearance in the United States, and its point of origin remains unknown. A brief history of the discovery of the disease in the six States where it has been positively identified is given in the following paragraphs.

TEXAS

Discovery in Texas of the disease that was later named peach mosaic has been recounted in preceding pages.

In the course of their regular surveys on distribution of the phony peach disease (5), eradication inspectors in 1931 and 1932 observed peach mosaic in eight counties. The total number of mosaic-affected trees seen was 181, and the number of orchards infected was 46.

COLORADO

A peach disease new to Colorado was recorded by Bodine in Mesa County on July 12, 1931, at which time a total of seven trees in three adjoining orchards were found to be affected. The new disorder was observed in subsequent years, and on May 14, 1934, Bodine² identified the disease as peach mosaic, which identification was confirmed by Hutchins on June 19 of the same year. The rapid spread of the disease and its subsequent checking through eradication are

² BODINE, E. W. OCCURRENCE OF PEACH MOSAIC IN COLORADO. U. S. Dept. Agr., Bur. Plant Indus. Plant Disease Rptr. 18: 123. 1934.

recounted in the section dealing with control (p. 42). In 1935 thorough inspections were carried out in the counties of Mesa, Delta, and Montrose, but only in Mesa was peach mosaic found to occur. History, symptomatology, varietal behavior, and other matters pertaining to peach mosaic in Colorado are discussed in a recent bulletin by Bodine (1).

CALIFORNIA

In 1933 the existence in a limited district of southern California of a disorder in peach trees, of unknown cause, was called to the attention of officials of the Citrus Experiment Station at Riverside by W. M. Winslow, county farm adviser of Riverside County. An investigation revealed that during a few preceding years this disease had been observed occasionally by members of the station staff and that it was known to a few growers. However, its cause was entirely obscure, and previous to 1933 it had not appeared to be important. Tentatively, it was designated "the 1933 peach disease" (7).

In 1934 the new disorder was observed to be much more prevalent in orchards where it had been seen the preceding year, and additional plantings in the same vicinities were becoming affected. H. S. Reed and others came to the conclusion that it was not little leaf, coryneum blight, or any peach disease previously known in California. Investigations were begun to determine the cause of the disease, and in February 1935 inoculation experiments that included root and scion grafts were made by Reed. Similar work was continued by Thornberry during the growing season of the same year.³

As these experiments matured it became evident that the new disease was infectious and of the mosaic type. The behavior of affected orchard trees, particularly in their leaf and fruit characters, suggested that the disease was similar to peach mosaic as described from Texas and Colorado (8).

That the 1933 peach disease in southern California is identical with peach mosaic was definitely confirmed in the spring of 1936 by Hutchins, who has studied the disease in other States. This confirmation was based on the following observations: (1) Nursery trees inoculated the previous year by Reed and Thornberry showed unmistakable symptoms of peach mosaic in the foliage; (2) affected orchard trees of varieties in which peach mosaic is known to develop in its most characteristic form showed positive symptoms of the disease both in retarded foliation and in mottling of the leaves; (3) for trees of peach varieties exhibiting large pink flowers, the disease produced breaking in the color patterns of the petals that were identical with this behavior, as previously found by Hutchins for peach mosaic in Texas.

³Owing to the obscure nature of this new peach disease at the time of its discovery in southern California, together with the possibility that a complex of physiological conditions might contribute to the cause, the early investigations were undertaken by H. S. Reed, in charge of the Division of Plant Physiology of the University of California Citrus Experiment Station. As the work progressed and the spread of the disease was recorded, Reed realized that an infective agent might be the cause of the malady. The Division of Plant Pathology of the Citrus Experiment Station was then invited to lend its efforts in behalf of the project, and in April 1935 H. H. Thornberry was appointed to develop the pathological phases of the investigations in collaboration with Reed. Late in 1935 both Reed and Thornberry entered upon other duties elsewhere, and in March 1936 L. C. Cochran was appointed to continue the work for the Division of Plant Pathology. Data on results of experiments begun by Reed and Thornberry are being taken and the investigations are being continued by Cochran, in collaboration with the senior author.

UTAH, NEW MEXICO, AND ARIZONA

In the summer of 1935, State officials observed a new peach disease in the vicinity of Moab, Utah, which they suspected was peach mosaic. The authors visited the district in company with Utah representatives and confirmed the identification.

During the summer of 1936, inspectors for the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, discovered peach mosaic in several counties in New Mexico and in Arizona.

IDENTIFICATION

Common names of plant diseases are often chosen in such a way as to describe a distinctive character of the entire diseased plant or of one or more of its parts. It is, of course, understood that the most important diagnostic symptom from which a disease may derive its name may not be in evidence at all times in the affected plant. Furthermore, this symptom may be preceded, accompanied, or followed by other symptoms, one or more of which may serve as positive or confirmatory aids to identification at one or another season of the year.

The above usage applies particularly well to virus diseases of perennial plants like the peach. As will appear farther on, mosaic patterns in the leaves in spring constitute in general the most important diagnostic character of the peach mosaic disease, because this symptom has been seen in infected trees of many peach varieties, bearing or nonbearing, and of whatever age. However, this manifestation of the disease is distinctly seasonal in its appearance and may not be discernible in summer. Therefore, it should be understood that flower, leaf, fruit, and twig characters, apart from mosaic patterns in the leaves in spring, also may serve as excellent aids to identification of this disease.

Researches on peach mosaic are not complete, but within the compass of present investigations, as herein reported, the following description of the disease should enable the observer to recognize its characters in the field at one or more seasons of the year. Prominence is given to symptomatology as strikingly expressed in certain widely grown commercial peach varieties. In survey work, to facilitate early and positive identification of the disease in an orchard or in a community, it is suggested that, if present, these varieties should be inspected first. Less definite symptoms in some other varieties may then be better interpreted.

SYMPTOMS IN FLOWERS

An interesting new observation on peach mosaic was made by Hutchins, at Bangs, Tex., in March and April 1935. It was found that in the large-flowered peach varieties in which the petals turn pink, mosaic could be identified easily in the bloom by the abnormal breaking of solid pinks into islets, striations, and broad streaks or splashes of pink color, definitely demarked by fainter pink or white lines (fig. 2). Breaking of the petal color in this manner was observed from either the upper or the lower surface, and in many instances the designs produced on the two sides appeared to be identical and perfectly superimposed.

Transverse sections of the petals showed that the pink color is produced by a pigment dissolved in the sap of epidermal cells and that the sap of underlying cells is colorless. The white or faintly pink lines that penetrate the solid deep-pink areas and produce the



FIGURE 2.—Breaking in petal color, caused by peach mosaic: *A*, Streaks and fusiform islet spots prominent in three petals; *B*, streaks and prominent islet spots; *C*, streaks and faint islet spots; in one petal, no breaking; *D*, normal flower; white spots in petals not a mosaic character. *A*, *B*, and *C* are from the same diseased tree and show variations in patterns of breaking. Stamens removed to expose color patterns fully. Early Wheeler variety. Bangs, Tex. Natural size. (Photographed Mar. 25, 1935.)

breaking in diseased petals are formed by tissues, the epidermal cells of which have developed little or no color in the sap.

Breaking of petal color into sharply defined mosaic patterns as a result of the disease in the tree was observed in four peach varieties (Carman, Chilow, Early Wheeler, and an unnamed variety), all of which have large flowers that normally produce prominent pink tints in the petals. In newly expanded flowers of these varieties the

petals were nearly white and no mosaic symptoms were evident. Within a day or so after the flowers were fully expanded, however, pink pigmentation was noticeable and it increased from day to day until the full color was attained. A tendency to form mosaic patterns was first seen with the appearance of faint color in the petals, but the breaking did not attain its full value until the maximum intensity of color was reached. Finally, as the petals began to fade and wither, this mosaic symptom became much less brilliant.

For different flowers along the same mosaic-affected twig or limb, and for different petals in the same flower, there was considerable variation in the patterns and in the intensity with which the symptoms of breaking was expressed. Normal-appearing flowers sometimes were interspersed with flowers that were strikingly broken; occasionally in the same flower breaking was seen in some petals and not in others. Where breaking was observed in the flowers, leaves that developed later along the identical twigs or limbs showed mosaic symptoms typical of the disease for the respective horticultural variety.

Distinctness and appearance of breaking in individual mosaic-affected flowers were not observed to vary appreciably with the age or extent of the disease in the tree. In one instance an Early Wheeler tree 6 years old and in full bloom showed only one flower that exhibited breaking. In this flower the mosaic character was equally as definite as in the case of flowers of the same variety on trees completely diseased. The location of this flower on the tree was marked. Several days later, after the twig on which the flower grew had developed foliage, leaves near the flower and on the same twig showed the typical yellow discoloration characteristic of mosaic, but the disease was not discernible in any other locations in the tree.

It could not be said that the pathogen gained entrance through this flower, as it is hardly conceivable that the infection could have developed rapidly enough to show symptoms in so short a time. However, this case and others in which only one twig of a tree was found to show mosaic characters indicate that the disease in all probability may enter through the shoot and that it is possible for symptoms to appear locally, perhaps near the point of natural inoculation, before they are evident in the greater part of the tree.

For the small-flowered peach varieties opportunity was afforded to examine the bloom in mosaic-affected trees of Elberta, Belle (Belle of Georgia), and an unnamed yellow cling. Although the petal color of Elberta and Belle is pink and that of the cling is a deep brownish pink, in no case was any tendency to breaking observed in the flowers of these varieties (fig. 3). The disease in these trees, however, was identified later by mosaic discoloration of the leaves.

For all peach varieties observed the pistil and the stamens of flowers from mosaic-affected trees developed in an apparently normal manner (fig. 4), but frequently the petals were abnormally crinkled and in some cases were noticeably dwarfed. Pollen from flowers from mosaic-affected trees, whether or not the petals showed breaking, germinated normally.

The above observations on breaking and other flower characters of peach mosaic, first seen in 1935, were confirmed in the same Texas orchards in 1936, and in the latter year identical symptoms and be-

havior were observed in peach trees in Colorado and in southern California. The relative values of bloom and other characters for identification of the disease in several peach varieties are shown in table 1, page 38.

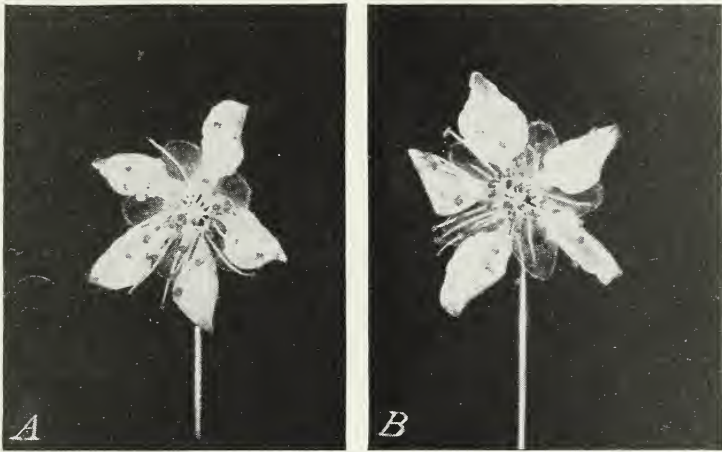


FIGURE 3.—Elberta peach flowers: *A*, From a mosaic-affected tree, showing no breaking in petal color for this variety; *B*, from a normal tree. Bangs, Tex. Natural size. (Photographed Mar. 24, 1935.)

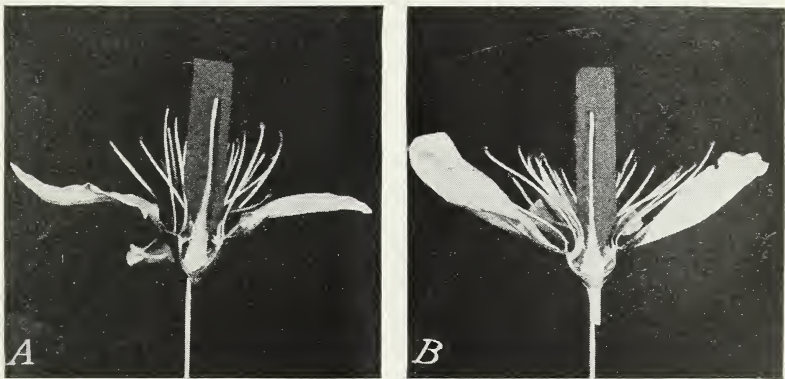


FIGURE 4.—Longitudinal sections of peach flowers: *A*, From a mosaic-affected tree, showing no abnormal characters in pistils and stamens; *B*, from a normal tree, Chilow variety. See text for discussion. Bangs, Tex. Natural size. (Photographed Mar. 24, 1935.)

In some respects positive identification of peach mosaic is more easily made by the character of breaking in the blooms, in the varieties where this symptom occurs, than by other manifestations of the disease. Fewer confusing symptoms have been observed in this than in other characters. Especially when the fusiform islet spots shown in figure 2 are definite and numerous in the petals, to the best of present knowledge it may be taken as proof that the tree is affected with the peach mosaic disease. Insofar as the authors are informed,

breaking in peach blooms is specific for peach mosaic and has not been described as a character associated with any other disease of the peach in the United States. Where this character can be used, that is, for bearing trees of large pink-flowered varieties, identification of the disease may be made from one to several weeks earlier than would be possible from the next successive seasonal manifestation, namely, mosaic patterns in the leaves.



FIGURE 5.—Peach twigs: *A*, Twig affected with mosaic, showing small, deformed leaves accompanying retarded foliage in the spring; *B*, normal twig. Elberta variety. Bangs, Tex. Natural size. (Photographed Mar. 31, 1936.)

RETARDED FOLIATION

For peach varieties typified by Elberta and J. H. Hale, in which mosaic leaf symptoms are severe, growth of early foliage and new shoots in spring develop faster on normal than on mosaic-diseased trees of the same variety (figs. 5 and 6). Conspicuously retarded foliage on account of the disease is of much shorter duration in west-central Texas than in Colorado and California, probably owing to differences in environmental conditions under which the trees are grown.

In Texas, for new cases of mosaic, where first symptoms of the disease are evident either in the entire shoot growth of the tree or



FIGURE 6.—Retarded foliage of a tree affected with mosaic (A), as compared with a normal tree (B), both of the Elberta variety and in the same orchard. Bangs, Tex. (Photographed Apr. 10, 1935.)

in only a few limbs, tardiness in growth development in spring may be less conspicuous than in cases of longer standing and is usually

confined to limbs or portions of limbs that show mosaic characters in a large percentage of the leaves. Within 2 or 3 weeks after leaf growth begins, the effect of retarded foliation in mosaic-affected trees is largely overcome and this symptom may no longer serve as an aid to identification of the disease. In Colorado and California, on the contrary, retarded foliation in diseased trees in spring is often extreme, in both old and new cases of the disease, and may be in evidence for many weeks (fig. 7).

In a block of trees of the same variety retarded foliation in one or more trees may attract the observer's attention from a distance,



FIGURE 7.—Extremely retarded foliation in several limbs of a tree affected with mosaic. Elberta variety. Palisade, Colo. (Photographed June 19, 1934.)

but in itself it is of little or no value as a positive diagnostic character of peach mosaic, because physiological conditions or other diseases may cause similar behavior in peach trees. The presence or absence of true mosaic characters must be determined from close inspection of each tree.

SYMPTOMS IN LEAVES AND LEAFY TWIGS IN SPRING

For purposes of identification, one of the most important characters associated with the peach mosaic disease is the presence of variously shaped yellow discolorations in the newly formed foliage in spring (figs. 8-12). In the same leaf, or in different leaves, these discolorations may vary in size progressively from tiny points, flecks, spots, and streaks to larger areas of yellow color, the latter sometimes

coalescing to involve almost the entire leaf surface and occasionally surrounding islets or patches of green color. Mottling is generally most extensive in the basal portion of the leaves, although occasionally it may be the apex that is most severely affected in this manner.

Veinlet clearing (etiolation or yellowing of leaf parenchyma cells in contact with or in proximity to a veinlet) in the form of tiny transparent flecks (figs. 8 and 10) has been seen frequently in leaves from mosaic-diseased trees of Elberta, J. H. Hale, and several other



FIGURE 8.—Advanced stages of peach mosaic in leaves from an artificially inoculated peach nursery tree: *A*, Lower half, coalesced discoloration; upper half, spots and veinlet clearing; *B*, spots and veinlet clearing; *C*, marginal and apex discolorations; *D*, lower half, almost complete discoloration; upper half, islet spots of normal-appearing tissue. All leaves show distortion on account of the disease. Natural size. (Photographed by transmitted light, May 19, 1932.)

varieties; in some varieties this symptom has not been seen. Without causing noticeable distortion of leaf tissues, this character, as observed by transmitted light, may be manifested in the form of only a few cleared veinlets in the basal portion of the leaf, or, in scant or abundant numbers the flecks may be distributed throughout the entire leaf blade. Some trees affected with mosaic may show no veinlet clearing in the leaves; others may show the symptom in few or in many leaves. In the spring this character may be present either singly or in company with the typical mosaic mottling in a given leaf. For a discussion of veinlet clearing in diseased foliage in summer see page 24.

In some cases the first leaves that put out from the bud in the spring may show mosaic mottling either before or after the leaf blades have expanded; in other cases, the first-formed leaves may



FIGURE 9.—Mosaic-affected leaves showing broad streaks of discoloration. Elberta variety. Palisade, Colo. Natural size. (Photographed May 8, 1935.)



FIGURE 10.—Veinlet clearing in basal portion of leaf from a tree affected with mosaic. Elberta variety. Bangs, Tex. Natural size. (Photographed Apr. 4, 1936.)



FIGURE 11.—New leafy shoot from mosaic-affected tree in the spring. First formed leaves show no mottling; recently formed leaves are variously mottled. Elberta variety. Bangs, Tex. About two-thirds natural size. (Photographed Apr. 3, 1936.)

be free from mottling, whereas leaves formed later may show severe mosaic discoloration (fig. 11). The latter may be true regardless of whether the new shoot shows appreciable elongation.



FIGURE 12.—Leafy mosaic-affected twig in spring. Above, normal-appearing leaf (left) in same whorl with mottled and distorted leaves. Below, leaves showing common type of mottling seen in mosaic-affected orchard trees when observer looks through foliage toward sky. Elberta variety. Bangs, Tex. Natural size. (Photographed by transmitted light, Apr. 2, 1935.)

Very young leaves, when severely mottled by mosaic, may wither and fall or may assume irregular shapes as the blades expand. Chlorotic areas of various sizes may fall out, leaving holes and emarginations. These tendencies of diseased leaves are no doubt augmented by mechanical injuries.

Leaves affected with mosaic are very apt to be crinkly throughout the portion of the leaf blade where yellow discoloration is severe, although in some cases the leaf is slightly or not at all deformed.

Upon close examination the foliage of mosaic-affected trees presents a strange assortment of characters. Leaves with or without crinkly contour, but showing mosaic discoloration in varying degree, may be interspersed with normal-appearing leaves in the same terminal or lateral whorl (fig. 12). The severity of mosaic leaf discoloration along a branch, a twig, or an elongated new shoot may vary greatly in the different leaves; some leaves may show slight symptoms, some may show severe symptoms, and still others may be entirely free of all mosaic discolorations and appear normal (fig. 11).

All types of mosaic leaf discolorations common to a variety may be found in the same locality and frequently in the same tree, or a considerable degree of selectivity for one or another type may be evident respectively in different sites or localities. The type shown in figure 9 has been seen less frequently in Texas than in Colorado, California, and Utah. In Colorado, for the Elberta variety, it was noted in 1935 and in 1936 that the streak type (fig. 9) predominated on some sites, whereas on other nearby sites the types shown in figures 8, 11, and 12 predominated.

Lateral twigs several inches long may be interspersed along a limb that exhibits mosaic characters throughout its entire length, showing, respectively, the following characters: (1) Twigs with all leaves showing mosaic; (2) twigs with some leaves showing mosaic and some normal; and (3) twigs with all leaves normal. For other limbs all leaves may show mosaic. This behavior is true for trees that were definitely affected with mosaic in all branches the previous year, as well as for new cases in which either the entire tree or only a few limbs are visibly affected with the disease.

Whereas the natural green color of a normal peach leaf is so intense as to render the tissues nearly opaque in transmitted light, the yellow spots of a mosaic-diseased leaf are translucent and transmit a yellowish light. This feature is of value in examining individual leaves or in inspecting orchard trees. In the case of a tree showing mosaic of the leaves in spring, if the observer looks through the foliage toward the sun or the sky the yellow spots in the leaves stand out in strong contrast against the natural green of unspotted portions of leaves (fig. 12).

The early mosaic mottling in the leaves is more or less fugitive in most of the peach varieties observed (4). As the spring season advances, the yellowish spots begin to disappear, and by midsummer they may be greatly altered or no longer in evidence (p. 18). Greening of areas previously marked as yellow mosaic spots in leaves was observed in Texas in 1935. By April 8 chlorotic areas that had been very characteristic a week earlier were disappearing, and the color of the tissues was approaching a natural green. On this date, however, leaves on some other trees still exhibited well-defined mosaic spots. There is considerable evidence to support the view that warm temperatures have an important influence in bringing about the disappearance of chlorotic discolorations in some virus diseases of other kinds of plants, and an experiment reported by Cation (2) indicates that under some conditions the same may be true for the early spring mottling of the peach mosaic disease.

In new cases of peach mosaic the first appearance of symptoms in infected limbs in late spring and throughout the remainder of the

vegetative period may be attended by abnormally short internode formation, accompanied by tufting of foliage at the terminals of



FIGURE 13.—Termination of incubation period of peach mosaic, as indicated by symptoms of the disease in a rapidly growing shoot. Above, tufted foliage at shoot terminal; below, flecks appearing in normally formed leaves. Elberta variety. Natural size. Compare with normal shoot of same variety shown in figure 14. (Photographed May 15, 1932.)

growing shoots (figs. 13 and 14). The tufted leaves usually show mosaic symptoms of one or another description, although they may or may not be mottled. Flecking or veinlet clearing is frequently evident in the normally formed leaves subtending the clustered termi-

nal growth. Although these symptoms are very striking in Early Elberta, Elberta, J. H. Hale, and some other varieties, they may be



FIGURE 14.—Shoot from normal Elberta tree, for comparison with mosaic-diseased shoot shown in figure 13. Natural size. (Photographed May 15, 1932.)

extremely mild or absent in Carman, Early Wheeler, Phillips Cling, Salwey, and others.

SYMPTOMS IN LEAVES AND LEAFY TWIGS IN SUMMER AND FALL

The appearance of the foliage of mosaic-affected trees in summer and fall differs in many respects from that seen in spring. Here,

again, the character and intensity of mosaic symptoms may be notably different for some varieties as compared with others in the same orchard and may vary somewhat for trees of the same variety when grown under different conditions.

For the seasons under discussion, two general classes of mosaic symptoms in twigs and foliage may be seen, namely, (1) symptoms in trees that showed the disease in early spring, and (2) symptoms in trees that grew normally in early spring but developed the disease at some time during late spring, summer, or early fall.

SUMMER AND FALL SYMPTOMS IN TREES THAT SHOWED MOSAIC IN EARLY SPRING

In mosaic-affected trees in spring profuse branching of twigs frequently takes place from the terminal buds of the previous year, and this is accompanied by a peculiar arrangement of the leaves, as the season's growth progresses (fig. 15). Elberta and J. H. Hale are among the varieties in which these symptoms of the disease are commonly seen, whereas in Carman, Early Wheeler, Triumph, and some other varieties, branching of this character is rarely produced.

Mosaic-affected leaves that were mottled in spring present a variety of symptoms in summer and fall. In order to study seasonal symptom changes in identical leaves, the following experiment was performed. In Texas during early April 1935 diseased leaves of the Elberta type were so marked as to outline on the surface the location of mosaic discolorations of various shapes and sizes. When these leaves were examined in summer it was seen that (1) in some leaves all yellow discolorations had disappeared and, with or without distortion, the leaf blades were entire; (2) in some leaves a number of the marked spots retained yellow discoloration in altered intensity and form, whereas other marked spots in the same leaves had become green or were excised; (3) for several leaves in which small circular spots had been marked, particularly in the distal portion of the blade, these spots in summer were either raised and accompanied by pitting of the lower leaf surface immediately beneath them, or they had been neatly excised, leaving perforations of the size of the original spot. Pitting was not present in connection with a type of noninfectious chlorotic spot that was abundant in otherwise normal trees in the same orchard.

For the Elberta variety, summer symptoms in old mosaic-affected leaves are shown in figure 16. Leaf *A* shows slight distortion, irregular mottling, a few excised areas, and four raised spots about the size of a pinhead, located 1 inch from the petiole on the right longitudinal half of the blade. Leaf *B* shows general, even discoloration accompanied by distortion at the base and scattered excised areas. Leaf *C* shows mottling at the base, severe excision of tissues, and numerous raised and discolored areas of pinhead size in the distal portion of the blade.

Summer symptoms in old mosaic-affected leaves of the Early Wheeler variety are shown in figure 17. Leaf *A* shows slight distortion in the basal portion and two large brightly colored areas accompanied by distortion in the distal portion of the blade. Leaf *B* shows irregular streaking along the margins of the blade, together with excised areas. Leaf *C* shows mottling and severe emargination.



FIGURE 15.—Mosaic symptoms in summer in trees that were severely diseased in spring: A, Arrangement of rolled and distorted leaves on whorls of the current season's growth originating near the terminal of the previous year; B, small limb from center of group shown in A; leaves removed to expose whorl of current season's twigs. Elberta variety. Bangs, Tex. (Photographed Aug. 3, 1934.)

It will be noted that the general character of summer symptoms in old mosaic-affected leaves of the Elberta variety (fig. 16) differs from that of the Early Wheeler variety (fig. 17). Sufficient researches have not been completed to establish definite categories of symptom manifestation by groups of varieties, but with certain exceptions it has been observed that the yellow-fleshed freestone varieties, such as J. H. Hale, tend to show old-foliage symptoms roughly similar to

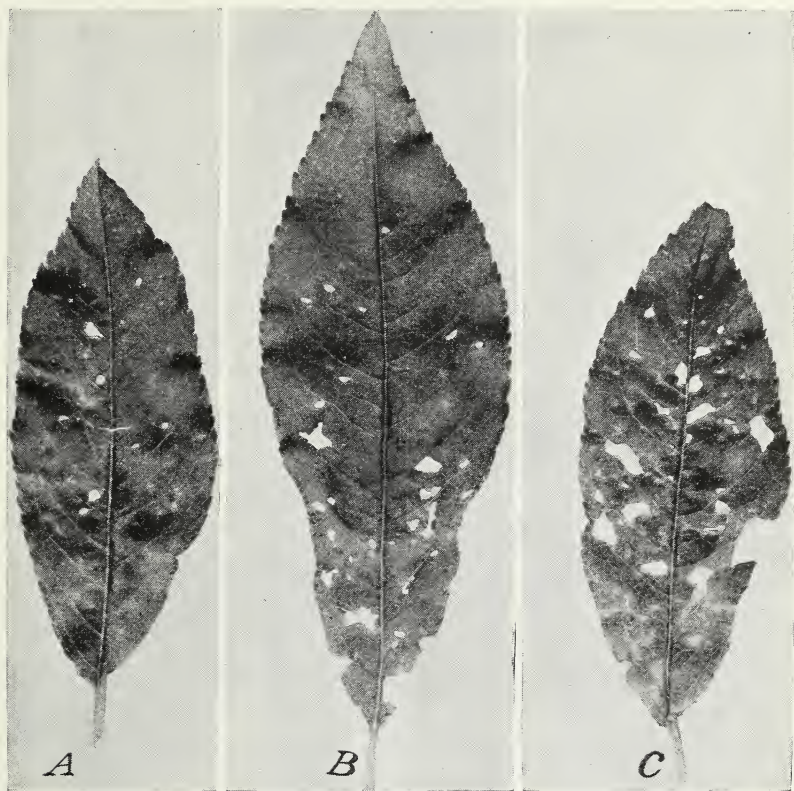


FIGURE 16.—Peach mosaic symptoms in summer in leaves that showed the disease in spring. Elberta variety. Bangs, Tex. Natural size. (Photographed Aug. 30, 1935.)

those of Elberta, whereas the white-fleshed varieties, such as Carman, tend to show old-foliage symptoms more like those of Early Wheeler. For all types of summer symptoms in old mosaic-affected leaves there may be much variation in prevalence and intensity in the same and in different varieties.

Trees that showed mosaic in early spring exhibit in summer and fall the branched growth and the leaf symptoms described in the last three preceding paragraphs. In addition to these symptoms, such trees also manifest different symptoms in twig and leaf growth produced in late spring and summer. The latter type of symptoms for mosaic-affected trees of the peach varieties under discussion (Elberta and others) are as follows:

Dwarfed growth is common at the terminals of both lateral and terminal shoots. Rapidly elongating shoots are likely to show the type of tufting illustrated in figure 13. If shoot growth has been slow, tufting is generally of the compact, rosettelike type shown in figure 18; this type is common in both terminal and lateral twigs of mosaic-affected trees showing growth retardation on account of a heavy crop of fruit, light pruning, drought, or general lack of vigor.



FIGURE 17.—Peach mosaic symptoms in summer in leaves that showed the disease in spring. See text for discussion. Early Wheeler variety. Bangs, Tex. Natural size. (Photographed Aug. 30, 1935.)

Even in trees thoroughly diseased with mosaic, some leafy shoots may grow in an apparently normal manner, and some may show short internodes for certain periods of growth and normal internodes for other periods of growth. Many shoots, either terminal or lateral, may be found to resemble that shown in figure 27 (p. 35).

In Texas, where retarded spring foliation caused by the disease (p. 10) is of short duration, lateral leaves on twigs affected with mosaic rapidly attain the approximate length of normal leaves. In Colorado and California, where retarded foliation in mosaic-affected trees in spring is in evidence for many weeks, the elongation of shoots on diseased limbs seldom exceeds 4 to 8 inches for the year, internodes are conspicuously short, and leaves rarely attain more than one-half to three-fourths natural size.



FIGURE 18.—Rosettelike tufted shoots, with many leaves perforated, crumpled, emarginated, and folded along the midrib; common in summer in slowly growing mosaic-affected trees of several varieties. Elberta variety. Bangs, Tex. (Photographed Aug. 5, 1934.)

Along these types of mosaic-affected twig growth, for the most part, leaf blades are abnormally folded along the midrib, mottling is uncommon, and a large number of leaves may show emargination, excision, and crumpling.

CHARACTERISTICS OF NEW CASES IN SUMMER OR FALL

Identification of new cases of peach mosaic in summer and fall may not be difficult in Early Elberta, Elberta, J. H. Hale, and some other varieties, but it may be extremely difficult in a different group of varieties typified in this respect by Guinn and Triumph. For the former group of varieties these identification characters are given in the following discussion.

Veinlet clearing (p. 13 and fig. 10), when present, is perhaps the most important symptom of peach mosaic for new cases of the

disease in summer and fall. Within an indefinite period after a leaf becomes severely flecked in this manner a marked tendency to excision of numerous small areas of intramarginal tissues may be observed throughout the flecked portion of the blade, although many leaves so flecked may remain entire. In leaves that have been flecked for several weeks tiny yellow spots often may be seen. Frequently these spots are slightly raised and the lower leaf surface immediately beneath them is pitted.

Tufting of terminal and lateral shoot growth has been described on page 17 and illustrated in figures 13 and 18. In summer and fall tufting may be seen as a first symptom of the disease and may occur either alone or in company with veinlet clearing.

In the late summer of 1935 Bodine marked for later observations several hundred trees showing very slight symptoms of peach mosaic. These symptoms consisted of veinlet clearing alone or veinlet clearing (with or without spots) accompanied by tufting of terminal shoot growth. Where veinlet clearing was the only symptom, as few as four to eight leaves so affected were seen in many individual trees. Where veinlet clearing was accompanied by tufting of terminal shoot growth, as few as one to three shoots so affected were seen in many individual trees. In the spring of 1936 all of the marked trees developed fully characteristic cases of peach mosaic.

As thus far observed, veinlet clearing occurs more generally throughout the vegetative season in Colorado and California than in Texas. In the latter State identification of new cases of the disease in summer and fall has been made for the most part from the characters of shoot terminals.

To what extent veinlet clearing may be correlated with varietal, environmental, and other factors has not been determined, but when present it is considered a very important manifestation of the disease.

In new cases of the disease, distribution of symptoms in the tree may be confined to one or to a few limbs or twigs. If first symptoms appear while growth is in progress they become more pronounced as the season advances and milder symptoms appear in previously unaffected portions of the tree.

OTHER CAUSES OF LEAF INJURY THAT MAY BE CONFUSED WITH MOSAIC

WIND WHIPPING

Wind whipping is a common cause of injury to tender leaves and succulent growing shoots of peach trees. When thus injured, leaves of normal trees may be severely emarginated, perforated, and distorted or crumpled in a manner closely simulating related types of malformations common to leaves of trees affected with mosaic. Observations on distribution of these symptoms in the tree may be of great value in the diagnosis of peach mosaic under such conditions, especially when typical mosaic leaf discolorations may not be in evidence, as is frequently the case in summer. For varieties subject to marked leaf deformities on account of peach mosaic, and where the disease has spread extensively through one or more large limbs of the tree, it is usual to find these symptoms more or less prevalent in all parts of the foliage mass along affected limbs, including leaves supported from the protected basal portions of the main arms as well as

those attached to the outer and more exposed branches and twigs. On the contrary, leaf deformities of this nature in normal trees are generally much more prevalent in the outer portions of the foliage mass and may be found sparingly, if at all, on protected inner twigs and branches.

CHAFING AND BRUISING

A confusing deformity and discoloration of peach leaves, not caused by mosaic, was seen frequently in southern California in the spring of 1936. Fully expanded leaves showed a crinkled surface throughout most of the length of the blade on both sides of the midrib, out to a line parallel with and about one-fourth inch distant from either margin. The crumbled tissues showed no yellowish discoloration, but along the lines of demarcation between this area and the smooth marginal tissues on either longitudinal half of the blade were numerous small yellow spots. Much less conspicuously there was some spotting of the marginal tissues.

This behavior of leaves was studied by Cochran,⁴ who offers the following interpretation of the cause: When the folded leaf began to expand and the upper epidermal surfaces of the longitudinal halves of the blade pulled away from each other along the leaf margins, thereby exposing the above-mentioned surfaces, a small insect, possibly thrips (which were frequently present), gained entrance and chafed the tissues along the line of separation. As viewed through a hand lens, the yellow spots appeared where the tissues were thus chafed.

Chafing and bruising of young peach leaves by wind-driven sand may cause small yellowish or whitish spots to appear in the tissues. For varieties in which leaf mottling due to peach mosaic is apt to be slight (see table 1, p. 38), this mechanical injury may cause false mosaic symptoms that may lead to some confusion in identification of the disease, notably where detached specimens are submitted for examination. In such cases, if determination cannot be made with the aid of a hand lens, it may be necessary to inspect the tree in place. Mechanical injury of this type is usually confined to nursery trees and low limbs of orchard trees, and its distribution in the tree may show some relation to the direction of prevailing winds. True mosaic symptoms should be looked for in protected leaves showing slight, if any, mechanical injury of this description.

NONINFECTIOUS CHLOROSSES

Noninfectious chloroses of one or another description, often due to malnutrition, climatic factors, or other causes, are of common occurrence in peach leaves, particularly in certain semiarid sections west of the Mississippi River. Leaf discolorations of this character may lead to much confusion in the identification of peach mosaic from foliage characters alone, especially for varieties such as Guinn, Triumph, and Tuskena (Tuscan), in which mosaic usually presents slight symptoms in the leaves. For the common noninfectious chlorosis, in which the tissues along the veins remain green and the interveinal tissues turn yellow, however, there should be no confusion with any of the observed types of infectious chlorosis or mottling

⁴ See footnote 3, p. 5.

produced by peach mosaic, because the two are quite distinct. It has been observed frequently that mosaic symptoms in the leaves in early spring may be evident before the noninfectious chlorosis of the interveinal type appears.

OTHER DISEASES

No difficulty has been experienced in differentiating between the leaf symptoms of peach mosaic and those of diseases caused by fungi or bacteria, with the possible exception of peach leaf curl caused by *Taphrina deformans*. In the very early stages of the latter disease, in spring, occasionally leaves may be crinkled in a manner that somewhat resembles types of distortion often seen in mosaic-affected leaves at that period, but usually it is not difficult to distinguish between symptoms of the two diseases. Leaf curl produces a rougher surface that is very apt to display reddish or reddish-purple tints instead of the smoother and yellowish crinkled areas common to mosaic-affected leaves. In advanced stages of leaf curl the two diseases display totally different symptoms.

SYMPTOMS IN FRUIT

In certain varieties the peach-mosaic disease causes variously shaped swellings and other irregularities of surface contour in the fruit, which give the latter a bumpy appearance. Bumpiness of this description, in the fruit, is first evident at about the stone-hardening period and becomes increasingly marked up to a few days before harvest. When the fruit remains on the tree until the flesh becomes somewhat soft and juicy, the definiteness of these individual protrusions is effaced to a degree by the natural swelling of the cells, which tends to leave the surface contour less deeply furrowed. The fruit of varieties showing pronounced bumpiness, however, may remain so misshapen as to render it unsuitable for the better commercial grades.

The bumpy swellings, which may vary greatly in size, appear mostly on the ventral or suture side of the fruit and extend from the apex to the cavity, which may be deeply creased (fig. 19, *A*). Occasionally the area of the bumpy surface also may include a portion of the dorsal side of the fruit.

A strange phenomenon frequently seen is the presence of zones of relatively smooth, normal-appearing areas, surrounded by or bordering on very irregular surfaces and separated from them by deeply furrowed lines. These areas may vary greatly in size and may be located on the bumpy suture (fig. 19, *A*), on the dorsal side of the peach (fig. 20, *A*), or on one or both cheeks (fig. 20, *B*).

There is a marked tendency for mosaic-affected fruits to be appressed longitudinally in such a manner as to accentuate the prominence of the apex (fig. 21, *A*). In this connection, the well-known variable behavior of the apex character in normal Elberta fruits should be taken into account. For the districts included in the present description of peach mosaic, Elberta fruits in Texas normally taper to a prominent apex, whereas in Colorado fruits of this variety normally show more fully developed cheeks at the distal end of the fruit, which may extend beyond an inconspicuously developed apex and meet in a crease across the latter.

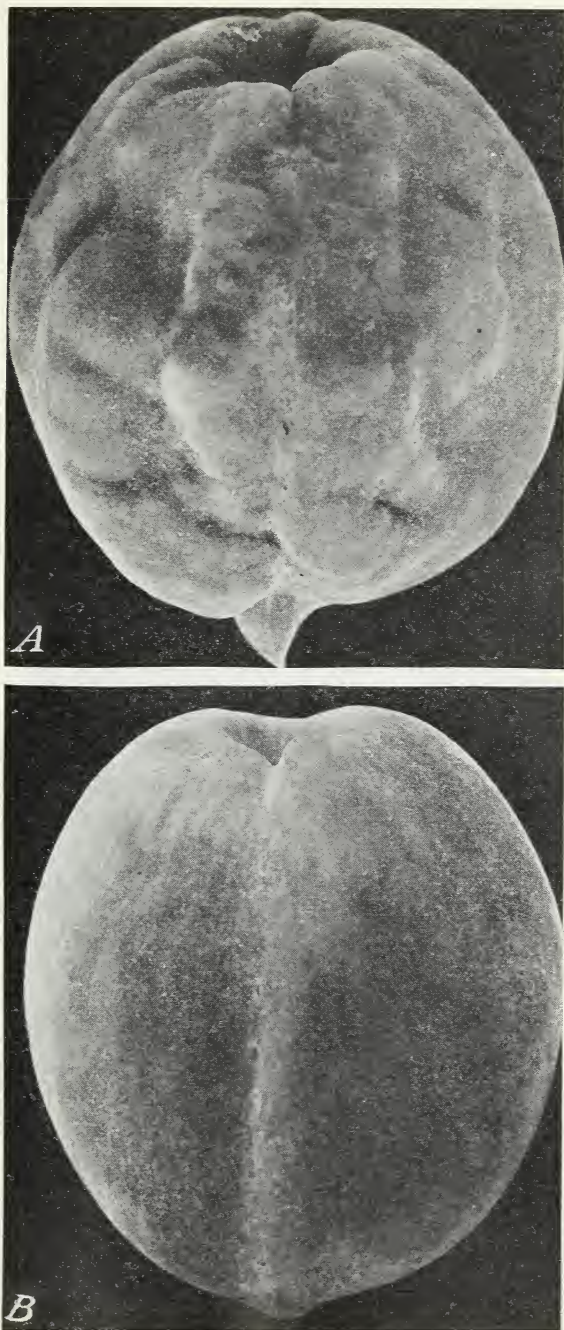


FIGURE 19.—Peach mosaic symptoms in fruit: *A*, Deeply creased cavity, bumpiness along suture, and prominent apex; *B*, normal fruit. Elberta variety. Bangs, Tex. Natural size. (*A*, photographed Aug. 7, 1935; *B*, Aug. 1, 1935.)

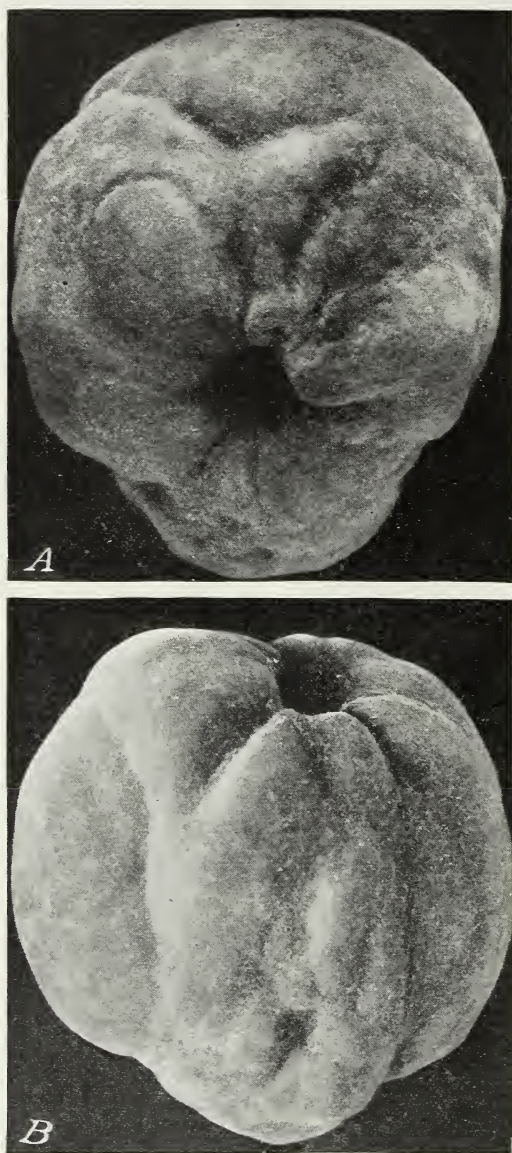


FIGURE 20.—Peach mosaic symptoms in fruit: *A*, Smooth, normal-appearing area adjoining irregular surface and separated from the latter by a deep crease; *B*, deeply creased cavity, prominent bumpy suture, and large zones of normal-appearing tissues on left cheek. Elberta variety. Bangs, Tex. Natural size. (*A*, photographed Aug. 3, 1935; *B*, Aug. 7, 1935.)

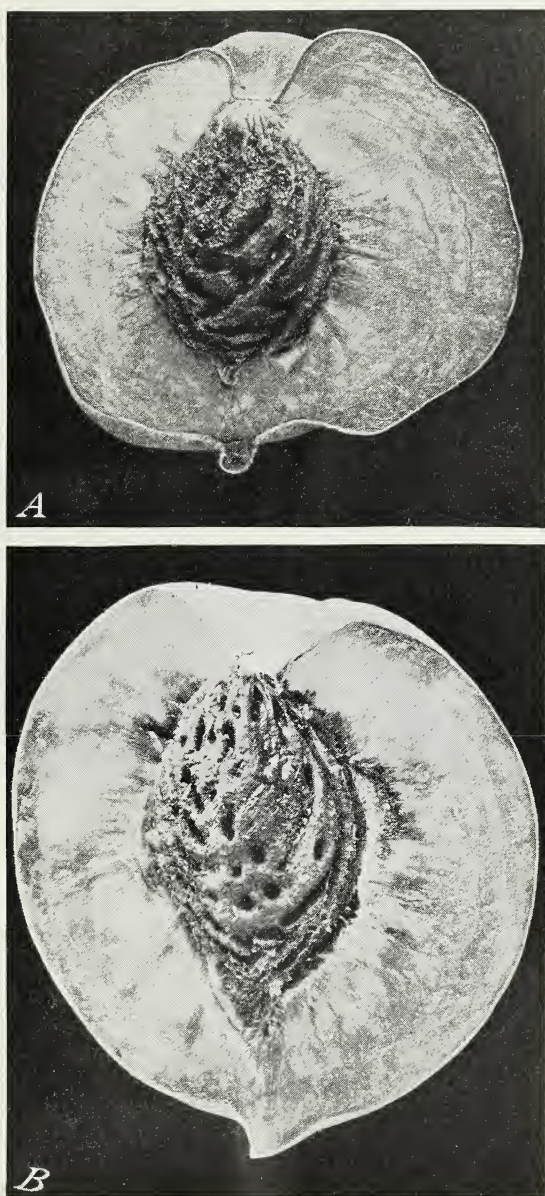


FIGURE 21.—Peach mosaic symptoms in fruit. Longitudinal sections exposing seeds: *A*, Appressed diseased fruit with prominent apex; *B*, normal fruit. Elberta variety. Bangs, Tex. Natural size. (Photographed Aug. 1, 1935.)

No color manifestation of peach mosaic has been observed to be constant in the fruit. The bumpy suture does not develop an unusual amount of red color, nor, with some exceptions, is there any other undue intensity of coloration in either the skin or the flesh. Red spots or rings have been seen occasionally on the fruit of the Elberta and J. H. Hale varieties (fig. 22).

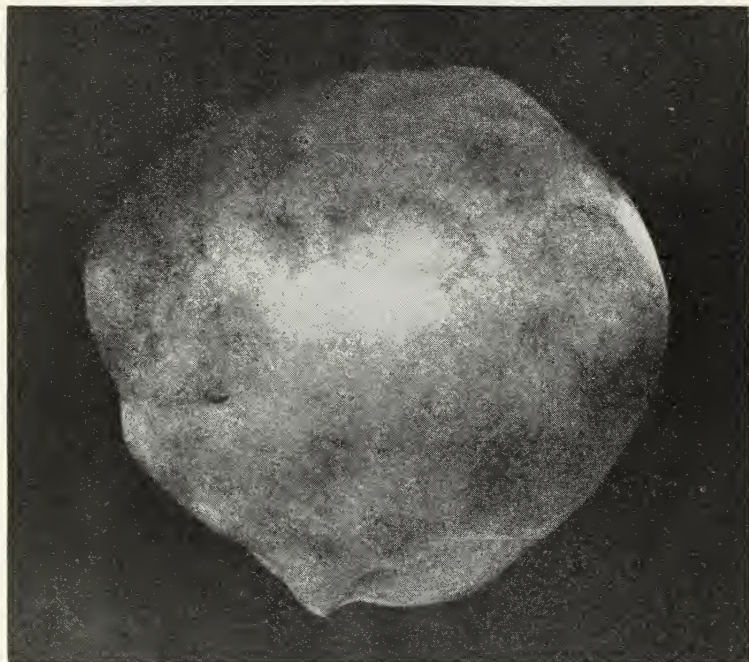


FIGURE 22.—Peach mosaic symptoms in fruit, showing surface discolorations caused by red spots and rings. J. H. Hale variety. Moab, Utah. Natural size. (Photographed Sept. 7, 1935.)

Fruit characters of the disease are manifested in varying intensities by the different peach varieties. Whereas accentuated symptoms may be found in the Elberta and J. H. Hale, fruits of the Guinn variety are entirely symptomless. In Texas in 1935 the flowers of an unnamed yellow cling variety showed breaking and the leaves were very severely mottled in the spring, but the fruit was only slightly bumpy and was not definitely enough marked in this way to render identification certain from individual specimens. However, when the mosaic-affected fruits were assembled in a group and compared with fruits from a normal tree of the same variety and in the same orchard, the former could be distinguished as mildly affected by the disease (fig. 23).

On a thoroughly diseased limb of a mosaic-affected Elberta tree, for example, most of the fruits will show the bumpy appearance, but occasionally a fruit of entirely normal appearance may be found on such a limb. Conversely, in new cases of mosaic most of the

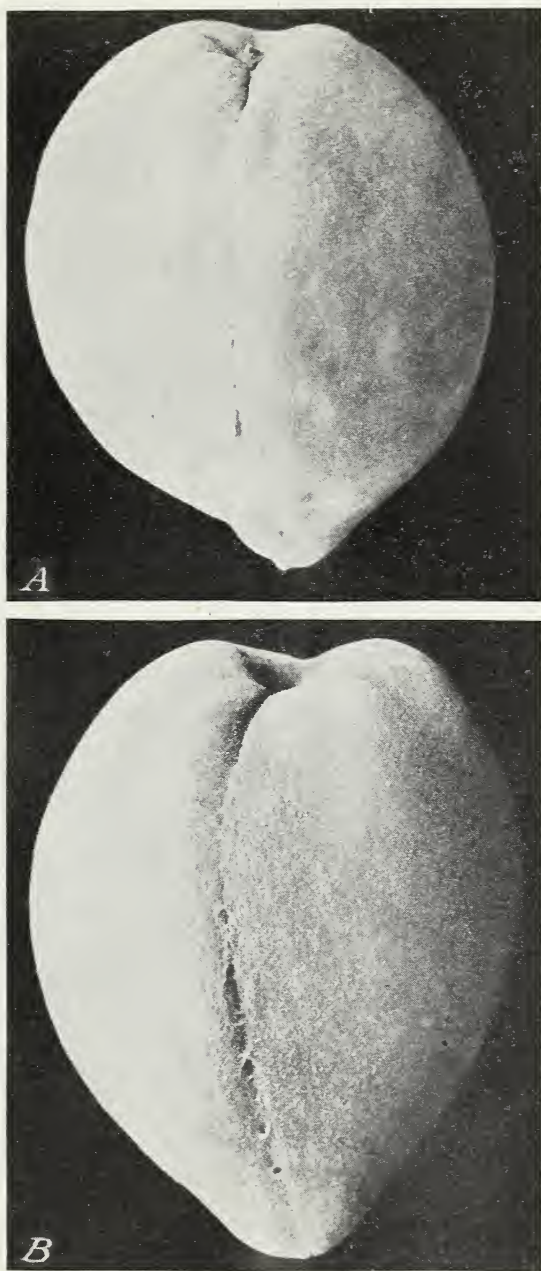


FIGURE 23.—Mild symptoms of peach mosaic in fruit, typical for some varieties: *A*, Diseased fruit; *B*, normal fruit. Unnamed cling variety. Bangs, Tex. Natural size. (Photographed July 27, 1935.)

fruits will be normal in appearance, but an occasional bumpy fruit may be found on one or more limbs that show no foliage characters of the disease.

Peach fruits are subject to bumpiness and various malformations, due to insect punctures, peach-leaf curl, mechanical injuries, and other causes. However, no swellings associated with any of these causes have been observed that closely correspond with those produced by peach mosaic in shape, number, and distribution on the fruit.

Mosaic-diseased fruits may ripen at the same time as normal fruits of the same variety, or they may ripen a few days later, and the latter behavior is frequently seen in distorted fruits on severely diseased limbs. There is no tendency to premature softening along the suture. The texture and flavor of mosaic-affected fruits may be somewhat inferior to that of normal fruits, but this character is not sufficiently extreme to be of value for identification of the disease.

Seeds from distorted peaches affected with mosaic are well formed but are likely to be smaller than seeds from normal fruit of the same variety (fig. 21), and the kernels are correspondingly reduced in size.

In Texas, seeds from mosaic-affected and from normal fruits were planted immediately after harvest in 1934. These seeds germinated in the spring of 1935. The seedlings from diseased seeds were similar in appearance to those from normal seeds and showed no mosaic at any time during the remainder of 1935 nor in the spring of 1936.

AFFECTED TREES IN SUMMER

Viewed from a distance, mosaic-diseased trees, even of the most severely affected varieties, in recent as well as in very old cases of the disease, may present abundant foliage in summer.

For the varieties that show the disease in its most characteristic form, such as Elberta and J. H. Hale, the exterior of the foliage mass of the diseased tree differs from the normal in the following particulars: Leaves affected with mosaic tend to be narrow, moderately rolled along the midrib, thereby exposing a portion of the lower leaf surface; lacking in gloss, emarginated, perforated, and crumpled. Because of the distribution of short internodes, together with profuse development of lateral and terminal spurs along the twigs, the leaves present a peculiar clustered arrangement, different from the normal, which at once catches the eye (fig. 24). These characters vary from light to extreme, depending upon the season's growth, the age of the disease in the tree, and the number of limbs affected.

In summer as well as in spring (p. 16), normal-appearing, well-leaved shoots several inches in length may originate from limbs thoroughly diseased (fig. 25).

For Carman, Early Wheeler, and some other varieties, the mosaic-affected tree as a whole in summer is much less strikingly abnormal in appearance than is the case for such varieties as Elberta and J. H. Hale; in the former varieties the disease may not be identified except on detailed observation of the individual leaves.

Wind whipping and other mechanical injuries of the foliage, which at times produce false symptoms of peach mosaic in normal trees, are common in both spring and summer (p. 24). In figures 13, 15,



FIGURE 24.—Peach mosaic in orchard trees in summer: *A*, Diseased tree; *B*, normal tree, Elberta variety. Bangs, Tex. (Photographed Aug. 10, 1935.)

18, and 26 are shown typical mosaic-affected Elberta leafy twigs of one or another description, such as may be found quite generally throughout the foliage mass of a mosaic-diseased tree of this variety in summer. Twigs from a normal Elberta tree in the same orchard



FIGURE 25.—Peach mosaic in orchard trees in summer. Cluster of normal-appearing leafy twigs (lower right) originating from a thoroughly diseased limb. Elberta variety. Bangs, Tex. (Photographed Aug. 2, 1934.)



FIGURE 26.—Peach mosaic symptoms in orchard trees in summer. Twig bearing many distorted, crumpled, perforated, and emarginated leaves, together with a few apparently normal leaves. Such twigs may be distributed throughout the length of diseased limbs, whereas twigs bearing somewhat similarly distorted leaves in wind-whipped normal trees are found only on the exterior of the foliage mass. Elberta variety. Bangs, Tex. (Photographed Aug. 5, 1934.)

are illustrated in figure 27; twig *A*, showing mechanical injury from wind whipping, was taken from the exposed outer portion of the foliage mass; twig *B*, in which mechanical injuries are very slight, was taken from the protected inner branches of this tree.



FIGURE 27.—False symptoms of peach mosaic in normal orchard trees in summer: *A*, Twig bearing distorted, crumpled, perforated, and emarginated leaves from wind-whipped exterior portion of foliage mass; *B*, twigs bearing uninjured leaves from protected interior portion of foliage mass. Elberta variety. Bangs, Tex. (Photographed Aug. 3, 1934.)

In summer, as in spring, where foliage distorted by mechanical injuries or other causes attracts the observer's attention and peach mosaic symptoms are in doubt, positive identification of the disease may require detailed examination of twigs and leaves. If the distortion is associated with the disease, crumpled foliage and other mosaic characters will be found throughout the length of the diseased limbs. If the distortion is not due to mosaic, the abnormal leaves and twigs will be found for the most part at the exterior of the foliage mass.

In certain Texas orchards an unnamed yellow-cling variety normally develops terminal growth of unusual appearance in summer which is tentatively called fuzzy top (fig. 28). Lateral twigs are numerous along the current season's terminal twig growth in the

upper portion of the tree and are accompanied by a peculiar character and arrangement of the leaves which cause extremely confusing false symptoms of peach mosaic when the tree is viewed from a distance. In normal trees of this variety these twig and leaf characters will not be found in the lower limbs and the interior por-



FIGURE 28.—False symptoms of peach mosaic in orchard trees in summer. "Fuzzy top", a condition common in an unnamed yellow cling variety, in which the clustered arrangement of abnormally folded leaves on profusely branched terminal twigs suggests symptoms of mosaic. Bangs, Tex. (Photographed Aug. 2, 1934.)

tions of the foliage mass, whereas if the tree has mosaic, leaf and twig characters similar to those shown in figures 13, 15, 18, and 26 will be seen throughout the length of affected limbs.

AFFECTED TREES IN WINTER

In the dormant condition, advanced cases of peach mosaic in such varieties as Early Elberta, Elberta, and J. H. Hale are easily

identified from the character of the twig growth. In figure 29, *A*, showing the disease in a tree of the Elberta variety, the spurlike



FIGURE 29.—Peach mosaic symptoms in orchard trees in winter: *A*, Limbs of a diseased tree showing spurlike lateral twigs and clustered or whorled terminal twigs; *B*, limbs of a normal tree. Elberta variety. Bangs, Tex. (Photographed Nov. 18, 1935.)

lateral twigs and the clusters of twigs that grew from the terminal buds of the previous season may be seen. A normal tree of the

same variety is shown in figure 29, *B*. These mosaic twig characters, as compared with the normal, are illustrated in detail in figure 30.

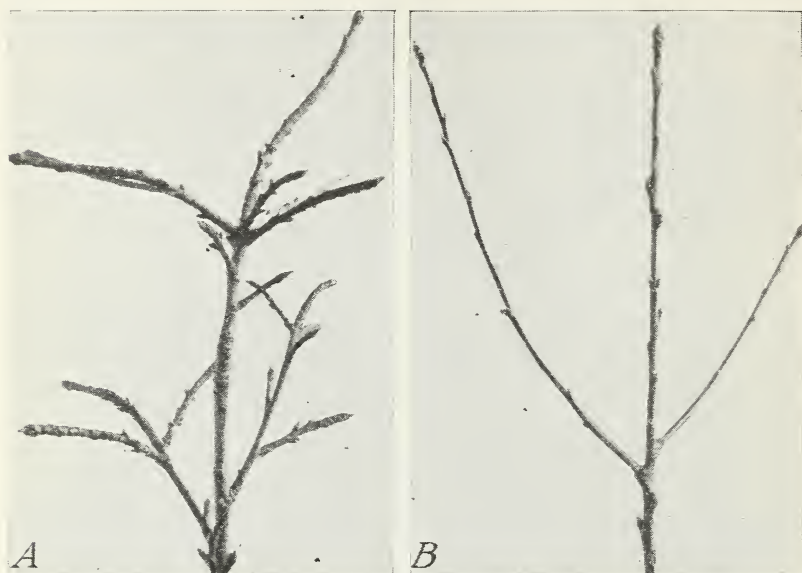


FIGURE 30.—Peach mosaic symptoms in orchard trees in winter: *A*, Diseased limb showing arrangement of terminal and lateral twigs; dwarfed growth with short internodes; *B*, normal limb. Elberta variety. Bangs, Tex. (Photographed Nov. 18, 1935.)

SUMMARY OF PEACH MOSAIC CHARACTERS

A summary of the principal characters of peach mosaic, insofar as they have been recorded, for several commercial varieties, is given in table 1. The varieties are grouped according to relative intensity of mosaic discolorations in the leaves, as follows: Group 1, pronounced; group 2, medium; group 3, slight. This information is introduced here as a guide to identification of the disease in the field. It should be recalled that symptom manifestation for a variety is somewhat variable under different conditions. The table will be subject to additions and corrections as further information is obtained.

TABLE 1.—Summary of principal characters of peach mosaic insofar as recorded for commercial varieties, grouped according to intensity of mosaic discolorations in leaves

Group and variety	Breaking in blossoms	Mosaic in leaves	Veinlet clearing	Bumpiness in fruit	Branching at twig terminals
Group 1:					
Chilow.....	Pronounced.	Pronounced.		Slight.	Medium.
Early Elberta.....	do.....	do.....	Pronounced.	Pronounced.	Pronounced.
Elberta.....	None.....	do.....	do.....	do.....	Do.
Halberta.....	do.....	do.....	do.....	Medium.	Do.
J. H. Hale.....	do.....	do.....	do.....	Pronounced.	Do.
Rio Oso Gem.....	Pronounced.	do.....	do.....	do.....	Do.

TABLE 1.—*Summary of principal characters of peach mosaic insofar as recorded for commercial varieties, grouped according to intensity of mosaic discolorations in leaves—Continued*

Group and variety	Breaking in blossoms	Mosaic in leaves	Veinlet clearing	Bumpiness in fruit	Branching at twig terminals
Group 2:					
Admiral Dewey.....		Medium		Slight	Slight.
Alexander.....		do.	Slight		Medium.
Babcock.....	Pronounced	do.			
Belle.....	None	do.		Slight	
Carman.....	Pronounced	do.	Slight	do.	Slight.
Champion.....		do.		do.	Do.
Early Crawford.....		do.		do.	Do.
Early Imperial.....	None	do.		do.	Medium.
Early Wheeler.....	Pronounced	do.			Slight.
Florence.....	do.	do.			Medium.
Lemon Cling.....		do.			
Mayflower.....	Pronounced	do.			Slight.
Paloro.....	None	do.		Slight	Do.
Rochester.....	Medium	do.		do.	Medium.
Salwey.....	None	do.		do.	Slight.
Group 3:					
Australian Saucer.....	Pronounced	Slight		None	Do.
Curry.....	None	do.		Medium	Do.
Greensboro.....		do.		Slight	
Guinn.....		do.	None	None	None.
Krummel.....	None	do.		do.	Do.
Lukens.....	Medium	do.		do.	Do.
Orange Cling.....		do.		Slight	Slight.
Phillips Cling.....	Medium	do.		do.	Do.
Simms.....	None	do.		None	Do.
Triumph.....	Medium	do.		do.	Do.
Tuskena (Tuscan).....	None	do.		do.	Do.

INCUBATION PERIOD

The precise incubation period of peach mosaic under conditions of natural spread is not known, because the vector has not been determined. In artificial bud and graft inoculation experiments in Texas, Colorado, and California, in 1935, peach nursery trees inoculated in the spring developed symptoms of mosaic during the growing season of that year, whereas trees inoculated in midsummer or later did not show mosaic characters until the spring of 1936, at which time the foliage showed very pronounced symptoms. By graft inoculation a large amount of the virus is introduced into the healthy plant; and the incubation period of the disease under these conditions may not be identical with that following natural inoculation. Data obtained in connection with eradication work in Colorado in 1934-36 (p. 42) indicate that the important natural spread of the disease may take place in the spring.

Symptoms accompanying the termination of the incubation period of the disease at different times during the vegetative season have been described in the preceding discussion. In the section on Control is given an account of the relative prevalence of new cases by seasons.

POSSIBILITY OF SYMPTOMLESS CARRIERS

Although the peach mosaic disease may not be identified during all seasons of the year in some peach varieties, no variety is as yet known to harbor the disease without showing identifiable symptoms at some time.

From the fact that symptom manifestation in Guinn and some other described varieties and in some seedlings takes the form of very slight discolorations in the leaves in early spring, it seems possible that a truly symptomless carrier of the disease may be found. It is recommended that test plants of a variety such as Elberta or J. H. Hale, in which symptoms of the disease are very pronounced, be employed in research work on symptomless carriers.

POSSIBLE OCCURRENCE IN OTHER SPECIES OF PRUNUS

It is known that some species of *Prunus* other than peach are susceptible to one or more of the peach virus diseases (6), and it is possible that among such species some may be susceptible to peach mosaic. Mottled leaves, abnormal shoot growth, and misshapen fruits, either singly or in combination, have been seen occasionally in almond, apricot, cherry, and plum, in the vicinity of peach orchards infected with the peach mosaic disease. Inoculation experiments are in progress to determine (1) whether bud grafts from such trees to peach will transmit a virus disease identical with peach mosaic, (2) whether symptoms may be produced in trees of these species after they receive mosaic-affected peach bud grafts, and (3) whether one or more of these species may act as a symptomless carrier of the peach mosaic disease.

METHOD OF SPREAD UNKNOWN

No vector of the peach mosaic disease has been reported, and the natural method of spread is not known.

In Colorado careful observations indicate that the disease is not transported by irrigation water. Under no orchard conditions has it appeared that the infective virus is inoculated into healthy trees through the agencies of soil, cultivation, mechanical contact, or pruning.

Numerous records show that under natural conditions the disease spreads readily, both among bearing and nonbearing trees. That pollen might transport the virus among bearing trees seemed possible, in view of the fact that breaking in the flowers is a symptom of the disease; however, experiments in Texas in 1935, in which flowers on normal trees were artificially pollinated with viable pollen from mosaic-affected trees, gave negative results and the disease was not transmitted in this manner.

One or more insect species have long been known to act as vector for many of the virus diseases of plants other than peach. Until very recently the agency of natural spread had not been determined for any of the peach virus diseases. With Kunkel's discovery that the leafhopper *Macropsis trimaculata* is a vector of the peach yellows disease (6), a very important line of attack is suggested for researches on vectors of other peach virus diseases, including peach mosaic.

SPREAD IN COLORADO

When the malady that later came to be known as the peach mosaic disease was first seen at Palisade, Mesa County, Colo., in 1931, a total of seven affected trees were found in three adjoining orchards.

From this small beginning and in the absence of effective control measures at the time, the disease spread rapidly in these orchards, and during the succeeding 4 years its area of distribution was extended to include a wide territory in this densely planted peach district of 573,497 trees along the Colorado River.

An alarming increase of the disease was first noted in May 1934. The group of three orchards where, in 1931, seven cases occurred was now heavily diseased, and by 1935 the destruction was almost complete. The percentages of mosaic-affected trees in these orchards for the years in which observations were made are shown in table 2.

TABLE 2.—*Spread of peach mosaic at Palisade, Colo., in orchards where the disease was first seen*

Orchard no.	Total trees	Trees showing mosaic in—			
		1931		1934	1935
	<i>Number</i>	<i>Number</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
1	1,149	3	Trace	75.5	97.5
2	356	3	do.	89.4	100.0
3	463	1	do.	53.4	96.3

Adjacent to the orchards mentioned in table 2, three additional plantings ranged, respectively, from 21 to 51 percent diseased in 1934 and from 85 to 95 percent diseased in 1935. In the same general vicinity nine other plantings ranged, respectively, from 10 to 32 percent diseased in 1934 and from 61 to 93 percent diseased in 1935.

Also, in 1934, three widely separated and important new mosaic colonies appeared, at distances of one-half mile to 2 miles from the original colony. Eight orchards were involved in the three new colonies, and from 16 to 63 percent of the trees in the individual orchards were diseased. In 1935 the accumulation of old and new cases in these orchards ranged, respectively, from 53 to 100 percent.

The survey of 1934 showed that from these four densely planted colonies of the disease, general spread to intervening and surrounding territories had been taking place rapidly. In the latter year 191 properties, exclusive of the 23 included in the four original colonies, showed the disease in percentages ranging, respectively, from a trace to 12 percent of the trees. By the spring of 1935 the disease had increased in these latter properties to include from 2 to 72 percent of the trees.

General spread of the disease over the Palisade district had reached astounding proportions by the spring of 1935. In this season 262 properties that were free of the disease in 1934 now showed mosaic cases ranging from a trace to 36 percent of the trees. Among the 538 properties for this district only 62 remained free of the disease.

The Palisade district is bordered on the west by the Clifton and West Orchard Mesa districts, which lie on opposite sides of the Colorado River. Spread of the disease to these and to other areas situated farther west, as determined in 1935, is shown in table 3.

TABLE 3.—*Spread of peach mosaic from Palisade district to outlying territories, in Colorado, by 1935*

Outlying orchard district	Distance from Palisade district	Total trees	Trees showing mosaic
	<i>Miles</i>	<i>Number</i>	<i>Number</i>
Clifton.....	1 to 6	38,302	439
West Orchard Mesa.....	1 to 8	47,129	31
Grand Junction.....	6 to 10	8,686	11
Redlands.....	11 to 16	38,413	2
Mack.....	25 to 30	1,676	0

CONTROL

For more than half a century it has been known that the control of virus diseases of the peach may be accomplished by eradication (5). The most devastating outbreaks of peach yellows, peach rosette, little peach, red suture, and phony disease have yielded to immediate removal and destruction of all visibly diseased trees when performed concurrently with frequent, efficient, and well-timed inspections of orchards, home plantings, nurseries, and trees escaped from cultivation.

As soon as it was known that peach mosaic is caused by a virus, therefore, eradication was recommended as the only effective means of control. Surveys and eradication are now in progress in several districts where this disease occurs. In Colorado outstanding results have already been achieved, as will appear from the following data contributed by Bodine.⁵

ERADICATION IN COLORADO

In the preceding discussion the rapid spread of the new disease in the absence of effective eradication measures has been described. With positive identification of the disease as peach mosaic in 1934 (1), actual removal of diseased trees was undertaken in the late summer and fall of that year. Periodic inspections together with eradication were continued throughout Mesa County during the growing seasons of 1935 and 1936.

The incidence of new cases of peach mosaic and the effectiveness of eradication in early spring as compared with eradication in late summer and fall are shown in table 4 and figure 31. Because of an incubation period of several months, under orchard conditions, total spread of the disease in a given year is not discernible until the following year, when most of the new cases become identifiable in spring. Eradication was first performed in late summer and fall of 1934; extensive spread was evident in 1935. Following eradica-

⁵ Peach mosaic surveys and eradication in Colorado have been organized, supported, and conducted in respective years by the following agencies: (1) In 1934, Botanical Section, Colorado Agricultural Experiment Station. (2) In 1935, Botanical Section, Colorado Agricultural Experiment Station, and Office of State Entomologist (State Department of Agriculture), cooperating; important contributions of funds by growers through their peach mosaic committee; assisted by Federal relief work project, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture. (3) In 1936, Federal relief work project, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture; Botanical Section, Colorado Agricultural Experiment Station; Office of State Entomologist (State Department of Agriculture), cooperating.

tion in early spring and throughout the growing season of 1935, a sharp decrease in the incidence of new cases was evident in 1936.

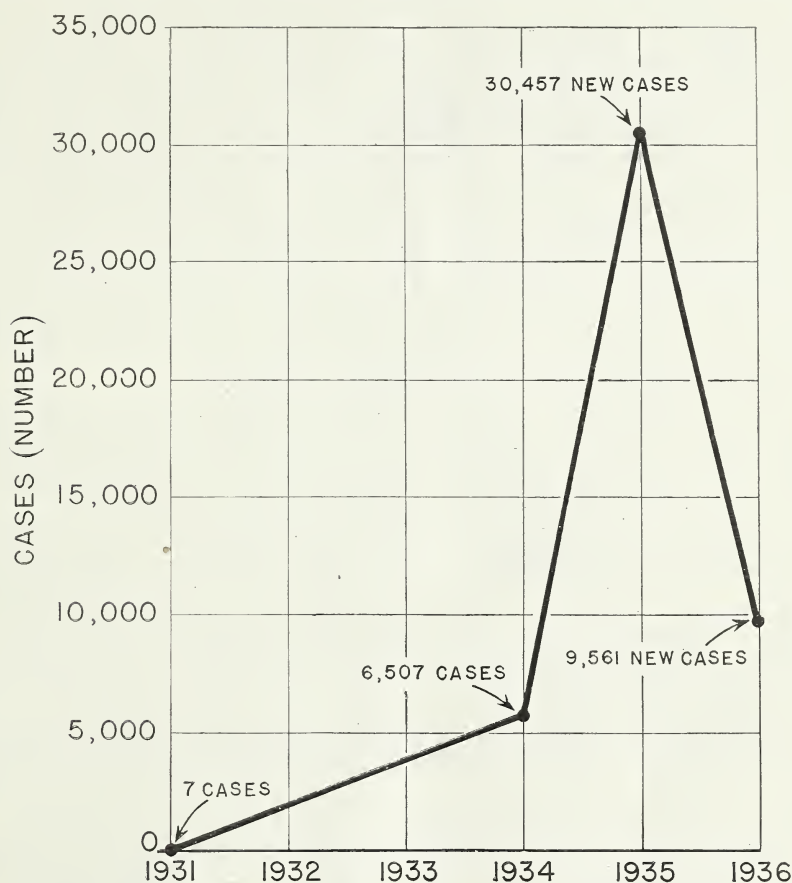


FIGURE 31.—Effect of eradication on spread of peach mosaic in Mesa County, Colo.

TABLE 4.—Effect of eradication on control of peach mosaic in the Palisade district of Colorado, showing spread of the disease in relation to late summer and fall eradication in 1934 and spring eradication in 1935

Plot no.	Orchards	Total trees	Trees showing mosaic in—		
			1934	1935	1936
	Number	Number	Number	Number	Number
1.....	4	4,895	26	588	169
2.....	1	3,704	5	275	144
3.....	3	3,678	25	582	140
4.....	5	3,935	66	557	178
Total.....	13	16,212	122	2,002	631

Table 4 shows the effectiveness of eradication in the Palisade district for representative orchard plots consisting of 40-acre areas where the incidence of the disease was not large in 1934. In con-

nection with these data it is significant to note that: (1) In 1934, of the 16,212 orchard trees included in the four plots, 122 (0.7 percent) showed mosaic and were removed in the late summer or fall of that year; (2) of the remaining 16,090 normal trees, 2,002 (12.3 percent) developed the disease in 1935. Of these new cases (in 1935), 1,643 trees (82 percent) showed symptoms and were removed in the spring of the latter year. The remaining 18 percent of new cases for 1935 first showed symptoms and were eradicated as follows: 168 trees in late spring and early summer, 104 trees in midsummer, and 87 trees in late summer and fall. (3) For 1936 (see footnote 5, p. 42) data are available only for inspections made in early spring and in late spring and early summer. Of the 14,088 normal trees that remained after the eradication work in 1935, 631 trees, or 4.47 percent, developed the disease in 1936. Of these new cases, 595 trees (94.3 percent) showed identifiable symptoms and were eradicated in the early spring of 1936. In late spring and early summer the remaining 36 trees (5.7 percent) developed symptoms and were eradicated.

In 1934 surveys showed that throughout Mesa County, which includes the Palisade district, 6,507 trees had developed mosaic. Of this number, 4,546 trees were removed in the late summer and fall of that year, and 1,961 trees showing mosaic were left standing, all of which were removed in the early spring of 1935.

In 1935 a total of 30,457 new cases were identified in the course of four inspections, as follows: (1) In early spring, 26,593 cases, or 87.3 percent of the total new cases of the year; (2) in late spring and early summer, 1,700 new cases, or 5.6 percent of the total for the year; (3) in midsummer, 1,249 new cases, or 4.1 percent of the total for the year; (4) in late summer and fall, 915 new cases, or 3 percent of the total for the year.

In 1936, when this circular was prepared for publication, only two surveys had been completed, during which 9,561 new cases were found and eradicated, as follows: (1) In early spring, 9,259 cases, or 96.8 percent of the total new cases for the year; (2) in late spring and early summer, 302 cases, or 3.2 percent of the total cases for the year.

Graphic presentation of data summarizing the incidence of new cases of peach mosaic by years, together with the effectiveness of eradication in different seasons of the year, are shown in figure 31.

The data on control obtained from complete and careful surveys before and after eradication show conclusively that the removal of diseased trees during late summer and fall failed to arrest the spread of the disease, whereas eradication in early spring and throughout the growing season was very effective for this purpose.

The rapidly ascending curve showing incidence of new cases of peach mosaic by years (fig. 31) indicates clearly that the entire peach industry of Mesa County was threatened with early ruin had control measures not been effectively inaugurated in 1935. Thorough eradication in the latter year procured encouraging results. Plainly, the rising incidence of new cases of the disease had been definitely arrested and the rate of spread was rapidly declining, as indicated by the descending curve for 1936. With the continuation of careful and complete eradication of diseased trees, it is anticipated that losses will be further reduced in 1937, and that after the next few succeeding years occurrence of the disease may be rare.

GENERAL REMARKS ON CONTROL

A thorough knowledge of the symptoms of the peach mosaic disease is requisite in inspection work.

Efficiency in eradication requires close inspection for slight and localized symptoms that may be evident in a very limited portion of the shoot of the tree. Where even the slightest positive symptoms are found the entire tree should be eradicated immediately, as such trees are a source of infection for healthy trees in the same and in adjoining orchards.

Irregularities among peach varieties in seasonal manifestation of peach mosaic symptoms have been described. Although a variety may present no mosaic symptoms at one season of the year, this should not be taken to mean that the trees are necessarily free of the disease. At Yucaipa, Calif., in an orchard where bearing trees of the Triumph variety were adjacent to bearing trees of the J. H. Hale variety, a survey in the summer of 1935 showed that nearly 100 percent of the J. H. Hale trees had mosaic, whereas with very few exceptions the Triumph trees were almost symptomless. In the spring of 1936, however, nearly 100 percent of the Triumph trees showed breaking in the flowers, which proved conclusively that trees of this variety were as susceptible to the disease as were the J. H. Hale trees. Similar comparisons among varieties have been recorded in Colorado and Texas. These records demonstrate the necessity of performing the recommended seasonal inspections in survey and eradication work.

The grower should understand that in carrying out control measures it is not practicable to do more than destroy visibly diseased trees at each inspection. Trees in which the infective virus is present but in which the incubation period of the disease is not terminated will show no symptoms, but these trees will develop positive mosaic characters later. Therefore, frequent and well-timed inspections are essential.

Pruning to remove all twigs or limbs showing symptoms of peach mosaic in trees partially diseased is ineffective as a control measure. Such symptoms do not mark the extent to which the infective virus is distributed in the tree, and, even though all visibly diseased growth is removed, the symptoms will reappear in such pruned trees during the same or the following growing seasons.

Severe pruning or dehorning of mosaic-affected trees may result in forcing a profusion of abnormal succulent twigs bearing tufted terminals and characteristic leaf symptoms (fig. 32). To eliminate the danger of spread from sucker growth of this description, prompt removal of stumps of affected trees to a point well below the collar should be included in an eradication program. It is a wise precautionary measure to burn diseased trees immediately after their removal.

In selecting buds, scions, or roots for purposes of commercial propagation, it is essential that the material should come from trees entirely free of the disease. It is considered unsafe to collect such material in localities where any mosaic-affected trees have been found within a year.

The virus of peach mosaic is deep-seated in the tissues of the trees and cannot be reached by application of safe orchard sprays.

With this disease, as with other virus diseases of the peach, cultural practices, application of fertilizers, injections of chemicals, or other treatments have never been observed to arrest the development of the disease in the tree or to effect a cure. Removal of the diseased trees remains the only efficient and practical method of control.

In no case has the causal virus of peach mosaic been observed to pass into the soil in an active condition. In Colorado replanting after removal of diseased trees has resulted as follows: In 1935 four orchard sites were replanted. In the first and second orchards a total of 12 Elberta nursery trees were planted in the holes from which dis-



FIGURE 32.—Character of growth forced from main arms of a severely dehorned peach tree affected with mosaic. Prompt removal of diseased stumps to a point well below the collar is essential in eradication. Elberta variety. Palisade, Colo. (Photographed June 19, 1934.)

eased trees recently had been removed. In the third and fourth orchards a total of 77 Elberta nursery trees were planted in 1935 on land where orchards 100-percent diseased were removed in 1934. In the summer of 1936, 16 months after planting, none of these young trees showed the disease. Therefore, it would appear that in the case of peach mosaic, as for other virus diseases of the peach, it is entirely safe to replant at any time after removal of diseased trees.

Although the peach mosaic disease may impair or destroy the commercial value of the crop in some of the most widely grown peach varieties, it has never been observed to kill the trees. An abundance of green foliage usually will have developed on mosaic-affected trees by midsummer. The functions of photosynthesis and of translocation and storage of elaborated food materials is sufficient to maintain life in the tree. This behavior emphasizes the importance of including home orchards, abandoned orchards, and trees escaped from cultivation in any eradication program for control of the disease.

Under natural environmental conditions that prevail in orchards and nurseries, trees affected by peach mosaic have never been observed to recover from the disease. In each succeeding year after the first appearance of the disease the tree continues to show symptoms and behavior typical of the disease in its horticultural variety. Improvement of foliage and twig growth in summer in trees that were severely affected in spring should not be interpreted to signify that the trees have been cured of the disease or that they are becoming immune to the action of the virus. These observations are based on extensive records made by the authors, respectively, in Texas, Colorado, and California.

Extremely important and as yet little explored fields of research on the peach mosaic disease, which may have an important bearing on control, include the following: (1) The host range of the virus; (2) varietal symptoms in the respective hosts; (3) symptomless carriers in the respective hosts; (4) intercommunicability among hosts; (5) vectors.

SUMMARY

The disease now known as peach mosaic was officially reported from Texas and Colorado in 1931. Its infectious nature and classification as a systematic virus disease of peach trees was established in 1932, at which time it was named peach mosaic.

The disease is now known to occur in Texas, Colorado, California, Utah, New Mexico, and Arizona.

Symptom manifestation of peach mosaic is variable among the horticultural varieties of the peach. Identification of the disease is made by one or more of the following symptoms: Breaking in the flowers, retarded foliation in spring, variously mottled and deformed leaves, twig abnormalities, and malformation of fruits.

The incubation period of the disease following inoculation by grafting is variable, depending in part on the season of the year during which the graft was made and the point in the tree at which the virus was thus introduced. Inoculations performed in spring are likely to result in the appearance of symptoms at some time during the same growing season. If inoculations are performed in mid-summer or fall, in most cases symptoms do not appear until the following spring. Under natural conditions of inoculation the incubation period of the disease is not known, but for a great majority of new cases in a given year symptoms first appear in spring.

Symptoms similar to those of peach mosaic have been seen in species of *Prunus* other than peach. Researches to determine the host range of the virus are in progress.

The natural vector of peach mosaic, presumably an insect, has not been determined.

The infective virus of peach mosaic is not spread from diseased to healthy trees by irrigation water, by pruning implements, or by other mechanical contacts.

In preliminary experiments the disease was not communicated to healthy trees by pollination with viable pollen from a diseased tree, and seedlings from mosaic-affected seeds grew in a normal manner. The disease is not communicated through the agency of the soil.

and replanting after the removal of affected trees may be made with safety at any time.

Cultural practices, fertilizers, orchard sprays, or injection of chemicals into the tree have not been effective for control of the disease.

Under favorable conditions for its spread, peach mosaic is one of the most contagious of the peach virus diseases. From its first appearance in a few trees in an orchard, and in the absence of effective control measures, the commercial value of an entire planting may be destroyed within 3 to 6 years, and rapid spread over a large peach-producing area may take place.

In an outbreak of peach mosaic in Colorado it has been demonstrated that thorough removal of diseased trees in early spring and at frequent intervals throughout the remainder of the growing season is proving effective in bringing the disease under control.

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